*Studies of Bioelectric Resistance in Overweight, Middle-Aged Subjects**

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Abstract Evaluation of a new instrument for measurement of bioelectric resistance has previously focused exclusively on assessment of body composition in young, healthy men at or near "ideal weight." A Weight Reduction Trial conducted in Jyväskylä, Finland provided an opportunity to evaluate the resistance method, both in terms of its relation to other anthropometric dimensions and its ability to predict body composition (percent body fat), in a group of overweight, middle-aged men and women along a continuum of levels of fatness. A series of anthropometric dimensions, bioelectric resistance, and underwater volume were measured using standardized techniques, and percent body fat (%BF) was estimated from body density. The correlation between replicate resistance measurements was extremely high ($r = 0.99$). Significant inverse correlations were observed between resistance and weight, weight/stature^2, body circumferences, and arm muscle area in both sexes, as well as sitting height, biceps and subscapular skinfolds, and body volume in women. Stature^2/resistance (S^2/R) was positively correlated in both sexes with all variables except triceps and suprailiac skinfolds, density and %BF (as well as upper arm and hip circumference, and other skinfolds in men). Stepwise and multiple linear regressions demonstrated that for men, hip circumference was the sole predictor of %BF, while S^2/R did not significantly contribute to the variance of %BF ($F_{1,27} = 0.367$; $p = 0.556$), and the model R^2 did not change (0.30 versus 0.31). Among women, in addition to hip circumference, thigh circumference, sitting height and age were also significant variables, and accounted for over 56% of the variance of %BF. As observed for men, S^2/R did not reduce any of the residual variance of %BF in women ($F_{1,43} = 0.310$; $p = 0.587$). Based upon these observations, the resistance technique does not appear to contribute to the estimation of percent body fat in middle-age, obese individuals.

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There has been increasing interest in the relations between various aspects of body size and body composition and the development of chronic diseases (Burton and Foster 1985; Bailey 1985), including cancer (Micozzi 1985). In order to test hypotheses about body composition and chronic diseases in the context of epidemologic studies, it is important to develop useful methodologies for assessing body composition that are applicable to large population samples in the field situation (Micozzi et al. 1986). The characteristics of the ideal anthropometric method for such applications include (1) accuracy, (2) reliability, (3) ease of use with minimal training or expertise required, (4) portability and mobility, and (5) low cost.

The bioelectric estimation of body composition represents a new methodology that potentially meets most of the above criteria. In the past, evaluation of a new instrument for measurement of resistance (RJL Body Impedance Analyzer, Model BIA 101) has focused exclusively on the assessment of body composition in young, healthy men at or near "ideal weight" (Cohn 1985; Lukaski et al. 1985). Due to biologic differences in patterns of body fat deposition by sex, age and levels of fatness, which may influence the behavior of methods for assessment of body composition (Borkan et al. 1985), it is important to evaluate new and existing methodologies across the range of human variability. A scientifically useful and biologically meaningful method for the assessment of body composition must be applicable to the obese or elderly, as well as to the lean and young.

A weight reduction trial in Jyväskylä, Finland provided the opportunity to investigate the relation between resistance and several anthropometric measurements along a continuum of levels of fatness in a group of overweight, middle-aged men and women. In addition, the utility of resistance for predicting body composition in this group of obese individuals was specifically assessed.

The Jyväskylä Weight Reduction Trial was conducted between 1980–1985 in Jyväskylä, a small city in central Finland. For the trial recruitment, a questionnaire was mailed to a random sample (N = 4101) of adults, ≥20 years of age, residing in Jyväskylä to ascertain current weight, stature, and willingness to participate. The response rate was 75%, of which approximately 10% reported information consistent with being overweight as determined by the formula weight/stature^2 (W/S^2). Thirty-five percent of these overweight respondents ages 20 to 64 yrs (N = 179) participated in the weight reduction trial, while 25 insulin-dependent diabetics were excluded. The participants were randomly assigned either to the "special intervention" (SI) or "ordinary care" (OC) groups. The SI group participated in a six-month free-living regimen of caloric reduction, including intensive dietary counseling, with exchange of free-living recipes and information on food preparation. The OC group was not placed on active caloric reduction, and received only a single interview to provide counseling on weight reduction. No further intervention followed the initial treatment period, but follow-up examinations were conducted at intervals of one, two and five years from the beginning of the trial. Both the SI and OC groups lost weight during the initial six-month period. In the SI group, the men lost an average of 2.5 kg/m^2 and the women lost an average 4.0 kg/m^2 in body mass index. In the OC group, the men lost an average 1.0 kg/m^2 and the women lost an average 0.5 kg/m^2. Over the subsequent five-year follow-up period, participants generally regained lost weight such that the SI group returned to an average 1.0 kg/m^2 less than starting weight, and the SI women 2.0 kg/m^2, while the OC men and women returned on average to starting weight. Weight gain over the 4.5 year follow-up period was gradual, such that participants were probably in metabolic equilibrium at the time of follow-up examinations.

Materials and Methods

Of the 152 participants who returned at the time of the last five-year follow-up examinations, bioelectric resistance and a series of anthropometric measurements were obtained in 134 participants and hydrodensitometry determinations were obtained on 82 participants. All measurements were obtained by the same observer on all participants.

Examinations were conducted on barefoot participants wearing only light underwear. Weight was obtained on two separate beam scales independently calibrated with constant weights prior to each measurement. Values were recorded to the nearest 0.5 kilograms. Correlations between duplicate measurements were high ($r = 0.99$) and the first weight reading alone was used in subsequent analyses. Stature and sitting height were measured using a fixed metal tape with the individual standing or seated, respectively, in an erect posture, and recorded to the nearest 0.5 centimeter. Skinfold thicknesses were measured to the nearest millimeter with a calibrated Harpenden skinfold caliper (British Indicators, Ltd.) at four specified sites: biceps, triceps, subscapular and suprailiac. Circumferences were measured with a linen tape according to the method of Krotkiewski et al. (1983), and recorded to the nearest centimeter at the following four sites: waist, through a point ⅓ of the distance between the xiphoid process and the umbilicus; hips, through a point 4 cm below the anterior superior iliac spine; thigh, around the thigh at a point ⅓ of the distance between the anterior superior iliac spine and the patella; and upper arm, at a point ⅓ of the distance between the acromion and the elbow. Calculations were made of waist/hip and waist/thigh ratios (Björntorp 1984; Seidell et al. 1985), arm adipose tissue and arm muscle areas (Heymsfield et al. 1982), and W/S^2.

Resistance was measured on 134 study participants using a four-electrode system placed at the wrist and at the ankle. Two source electrodes introduced a harmless radio frequency current into the participant, and two measuring electrodes placed between the source electrodes measured the electrical field of the biologic conductor. Each participant was measured recumbent with feet separated by at least 10 cm at the medial malleoli, or sufficient to physically separate the thighs. Any constrictive clothing or continuous metal objects around the limbs or body were removed. Body temperature was normal. Examinations were conducted following an overnight fast. Premenopausal women were measured within two days of cessation of menses. All participants voided prior to measurement. Duplicate measurements were obtained on each subject without moving the electrodes, and the average of the two readings was calculated. The instrument was calibrated daily with a test object. Based on the findings of Hoffer et al. (1969), the term stature^2/resistance (S^2/R), predictive of total body water, was used for the regression analyses.

Body volume was measured for a subset of participants (N = 82) as the volume of water displaced by total submersion of the subject in a specially constructed cylindrical tank with a bottom diameter of 76.75 cm and a height of 2 m. Readings of the water surface level before and after submersion were obtained in a calibrated vertical capillary tube of 5 mm diameter. Readings were taken on each individual, clad in a swimsuit, before climbing into the tank and after being totally submerged at least 5 seconds, under conditions of holding the breath both at maximal inhalation and at maximal exhalation. Special attention was given to avoid entrapping air in the swimsuit. Each body volume measurement was repeated 1–3 times with a 30 sec rest between replicate measurements; all were recorded, and their average was used for analysis. Water temperature was held similar to body temperature.

The measured body volume values at maximal exhalation were corrected for predicted residual lung volume using the method of Wilmore (1969). Body density (the ratio of weight/volume-exhaled) was calculated for each individual, and percent body fat (%BF) was estimated using the equation of Siri (1961).

Repeatability of the resistance instrument was determined using a simple Pearson's correlation between duplicate resistance measurements. It was not possible to assess the repeatability of the entire impedance method since only one electrode-instrument set-up was used on each individual, with one minute of rest between measurements, and without replacement of the electrodes. Repeatability between measurements was also determined for body volume with replicate underwater volumes on each subject. Means and standard deviations were calculated by sex for age, anthropometric variables, resistance, body volume and density, and %BF. The relatively small sample size precluded further stratification of subjects. Correlations between the various anthropometric measurements were calculated assuming linear associations (Pearson's correlations) since nonparametric Spearman's correlations did not materially differ.

A forward selection, stepwise linear regression procedure was used to first identify those study variables (exclusive of S^2/R) predictive of %BF. The selected independent variables were then entered into a multiple linear regression model, both with and without the term S^2/R, with %BF as the dependent variable. The overall statistical significance of the reduction in residual variance by S^2/R was tested using the partial-F statistic.

Results

The means and standard deviations for age, anthropometric measurements, resistance, hydrodensitometry, and %BF are shown in Table 1. Compared to women, men were taller, heavier, and had greater arm and waist

Table 1. **Measurements for Study Population by Sex (mean ± SD)**

Variable	*Men* *(n = 58)*	*Women* *(n = 76)*
Age (years)	46.6 ± 9.5	47.5 ± 10.5
Stature (cm)	175.5 ± 5.9	161.8 ± 6.6
Sitting Height (cm)	90.2 ± 2.6	84.3 ± 3.7
Weight (kg)	92.3 ± 9.5	80.1 ± 12.0
W / S^2 (kg/m^2)	29.9 ± 2.6	30.6 ± 3.9
Circumferences (cm)		
Arm	35.0 ± 2.3	33.5 ± 3.1
Waist	102.6 ± 6.4	92.9 ± 9.3
Hips	104.9 ± 6.5	108.4 ± 8.7
Thighs	59.3 ± 3.4	60.8 ± 4.5
Skinfold Thickness (mm)		
Biceps	8.4 ± 3.0	12.1 ± 3.6
Triceps	14.6 ± 3.9	22.8 ± 5.0
Subscapular	20.7 ± 5.2	23.2 ± 6.5
Suprailiac	19.3 ± 5.7	20.7 ± 6.7
Waist/Hip—Ratio	0.98 ± 0.04	0.86 ± 0.04
Waist/Thigh—Ratio	1.73 ± 0.10	1.53 ± 0.15
Resistance (ohms)	443.6 ± 40.7	509.3 ± 49.5
Body Volume (l)†		
Inhaled	90.4 ± 10.0	80.8 ± 13.3
Exhaled	87.2 ± 10.3	78.7 ± 13.2
Weight/Volume (exhaled) (kg/l)†	1.05 ± 0.02	1.03 ± 0.02
Body Fat (%)[1]	23.79 ± 7.64	32.26 ± 11.06

†N = 31 men and N = 51 women

circumferences, body volumes, and densities, while women exhibited greater W/S^2, skinfold thicknesses, hip and thigh circumferences, resistance, and %BF. For resistance, the correlation between duplicate measurements was very high ($r = 0.99$), and the average of the two readings was used in subsequent analyses. Similarly, among body volume replicate measurements, the correlation was high in both men ($r = 0.99$) and women ($r = 0.99$), and the mean value was used for subsequent analyses.

Table 2 shows the correlation of resistance measurements and S^2/R with other study variables by sex. Significant negative correlations were observed between resistance and weight, W/S^2, body circumferences, and arm muscle area in both sexes, as well as sitting height, biceps and subscapular skinfolds, and body volume in women. S^2/R was positively correlated in both sexes with all variables except triceps and suprailiac skinfolds, density and %BF (upper arm and hip circumference, and the other skinfolds in men as well). Correlation coefficients were generally greater among women, and for S^2/R than for resistance.

Table 2. **Correlations of Resistance and S^2/R with Other Study Variables by Sex***

	Men (N = 58)		*Women (N = 76)*	
	Resistance	*S^2/R*	*Resistance*	*S^2/R*
Stature	(+0.10)	0.54	(−0.06)	0.65
Sitting Height	(−0.002)	0.51	−0.19	0.59
Weight	−0.30	0.62	−0.51	0.68
W / S^2	−0.43	0.32	−0.54	0.38
Arm Muscle Area	−0.27	0.28	−0.41	0.45
Upper Arm Circumference	−0.21	(0.19)	−0.39	0.44
Waist Circumference	−0.29	0.40	−0.41	0.35
Hip Circumference	−0.18	(0.23)	−0.32	0.37
Thigh Circumference	−0.33	0.46	−0.42	0.56
Skinfold Thickness				
Triceps	(0.05)	(−0.09)	(−0.11)	(0.17)
Biceps	(0.006)	(−0.07)	−0.23	0.28
Subscapular	(0.04)	(−0.12)	−0.28	0.23
Suprailiac	(0.05)	(0.01)	(−0.18)	(0.07)
Arm Fat Area	(−0.02)	(0.03)	−0.23	0.30
Body Volume†	(−0.23)	0.60	−0.50	0.60
Body Density†	(0.008)	(−0.14)	(0.12)	(−0.03)
Body Fat (%)†	(−0.009)	(0.15)	(−0.12)	(0.04)

Values in parentheses not statistically significant ($p > 0.05$); $p \leq 0.05$ for all other correlation coefficients.

*The units of measurements are shown in Table 1.

†N = 31 men and N = 51 women

Table 3. **Multiple Linear Regression Coefficients, their Standard Errors and Model R^2 for Associations with %BF**

Variable	Model without S^2/R		Model with S^2/R	
	Coefficient	*S.E.*	*Coefficient*	*S.E.*
MEN (N = 31)				
Intercept	−56.74	23.18	−55.26	23.57
Hip circumference (cm)	0.78	0.22	0.84	0.25
S^2/R (cm²/ohm)	—	—	−0.12	0.19
Model R^2	0.300		0.310	
WOMEN (N = 51)				
Intercept	−29.65	30.45	−34.88	32.10
Hip circumference (cm)	0.61	0.16	0.61	0.16
Thigh circumference (cm)	0.86	0.35	0.92	0.37
Sitting height (cm)	−0.83	0.84	−0.73	0.39
Age (years)	0.28	0.12	0.27	0.13
S^2/R (cm²/ohm)	—	—	−0.13	0.23
Model R^2	0.566		0.569	

Results of multiple linear regressions of study variables on %BF are shown in Table 3. For men, hip circumference was the only variable to enter the regression model, and was a strong, positive predictor of %BF. When added to the model, S^2/R was not a significant predictor of %BF ($F_{1,27} = 0.367$; $p = 0.556$), and the two model R^2 values were virtually identical, with only approximately 30% of %BF variability being explained. Among women, in addition to hip circumference, thigh circumference, sitting height and age were also significant variables, and accounted for over 56% of the variance of %BF. As observed for men, S^2/R did not reduce any of the residual variance of %BF in women ($F_{1,43} = 0.310$; $p = 0.587$).

Discussion

We had the opportunity to explore the relationship between bioelectric resistance, an indirect method of body composition determination, and several anthropometric measurements, as well as %BF, in a population of obese, middle-age men and women. Although Hoffer et al. (1969) demonstrated that the prediction of total body water by bioelectric resistance was improved through adjustment for stature by the term S^2/R, the study evaluated a non-obese population. We believed it useful, therefore, to assess both resistance and S^2/R through correlation analyses in our study population. These showed greater correlation of both resistance and S^2/R to measurements of body size (e.g. body weight or volume) and lean body tissue (e.g. arm muscle area) than to indicators or estimates of body fat. The finding of stronger correlations with S^2/R rather than resistance is supportive of the study of Hoffer et al.

In this population, S^2/R did not contribute to the prediction of %BF in either sex, a finding supported by the very low correlation coefficients observed between S^2/R and %BF. The significance of hip circumference in each sex and thigh circumference in women is not surprising given the observed levels of obesity, as well as the distribution of body fat. Regarding the contribution of age and sitting height among women, %BF has been shown to be positively correlated with age (Chumlea et al. 1981), and it has been suggested that sitting height and age are inversely related (Chumlea et al. 1984).

Based upon these observations in overweight, middle-aged subjects, the bioelectric resistance measurement, as incorporated in the term S^2/R, does not appear to contribute to the estimation of percent body fat, either alone or in combination with other anthropometric variables. It is possible, however, that the resistance method may be useful in the prediction of body composition in other non-obese populations.

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